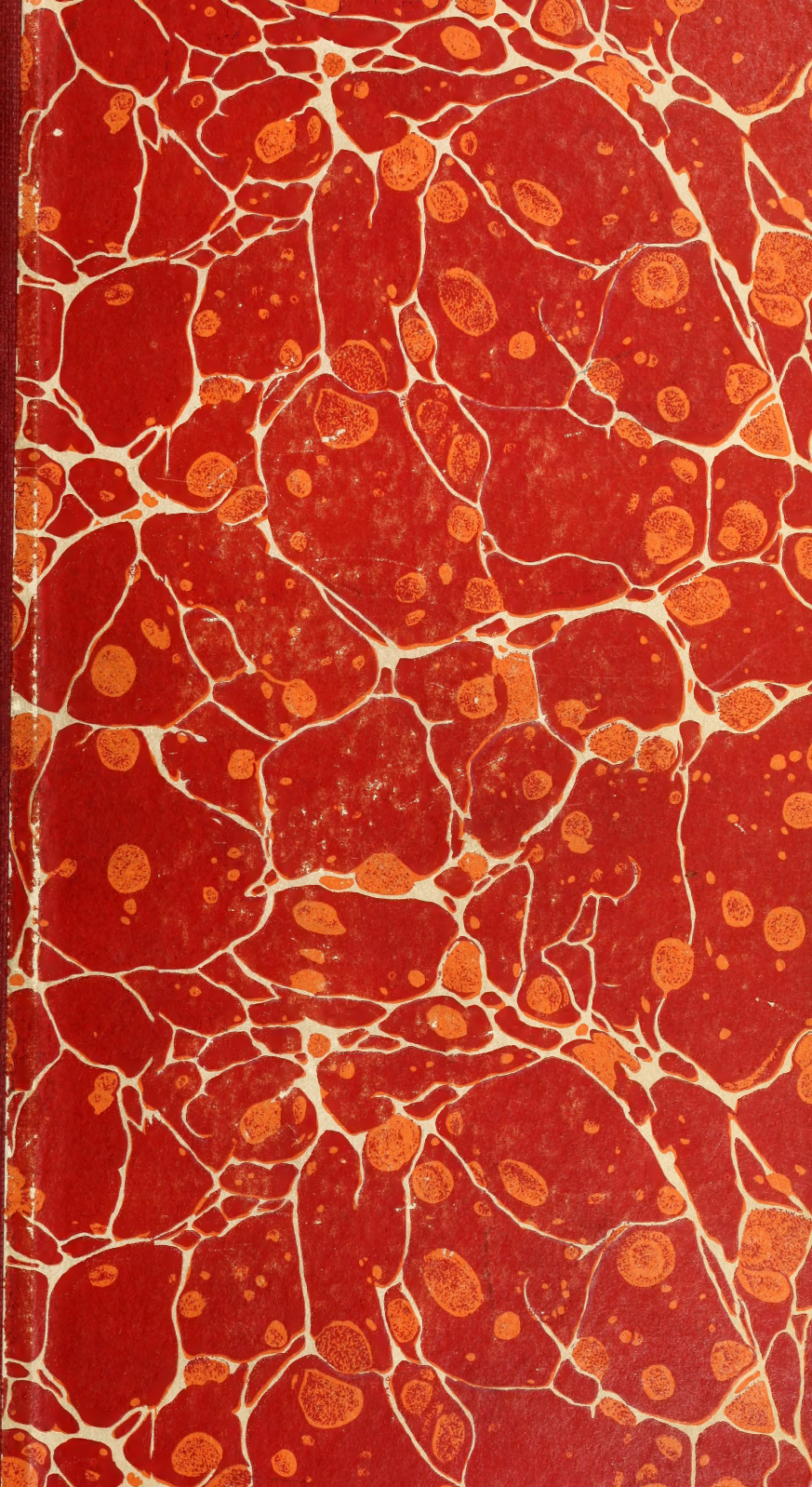
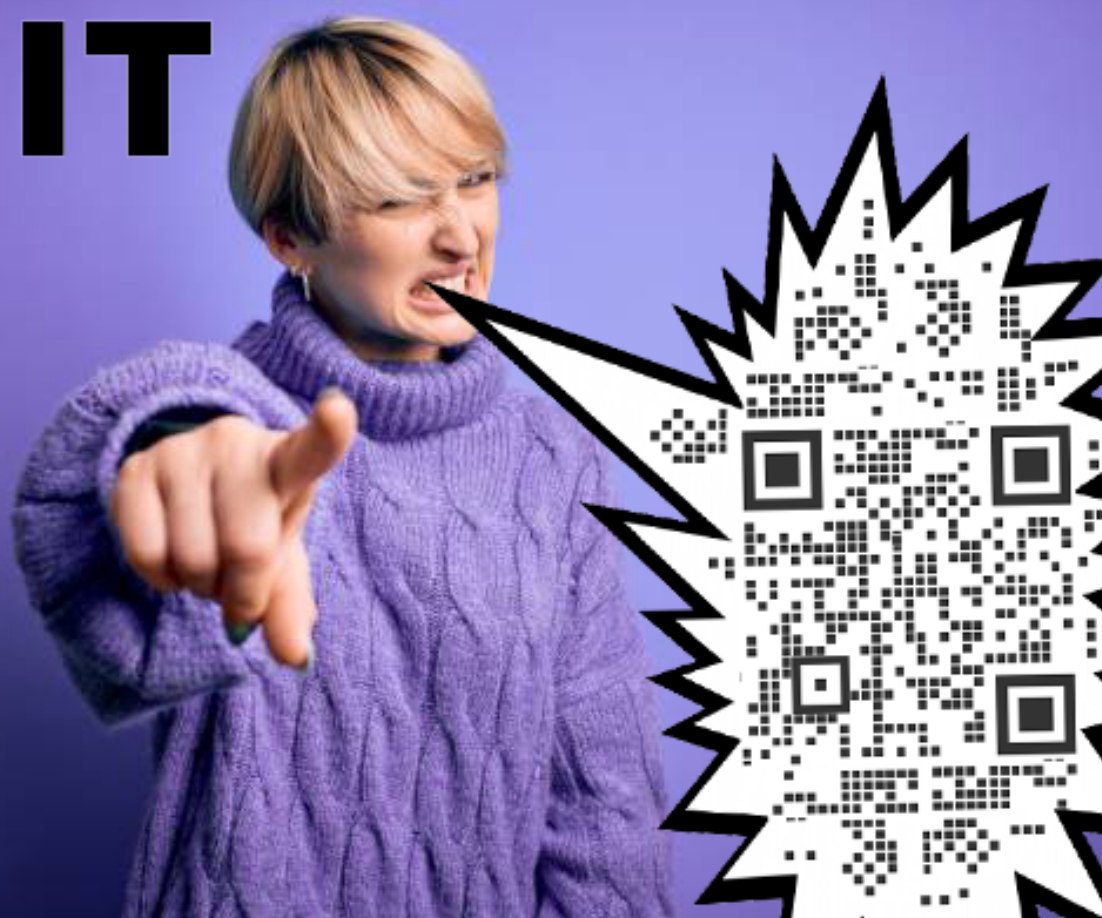




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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 85



Contribution from the Bureau of Animal Industry, A. D. Melvin, Chief.
April 27, 1914.

(PROFESSIONAL PAPER.)

THE COST OF PASTEURIZING MILK AND CREAM.

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INTRODUCTORY.

In the pasteurization of milk and cream there are two systems in use at the present time, known as the "holder" and the "flash" processes. The holder process consists in holding the milk or cream for about 30 minutes after it has been heated to the pasteurizing temperature of 140° to 150° F., either in the same apparatus in which the pasteurization takes place or in separate holding tanks arranged for the purpose, after which it flows to the coolers. In the flash or continuous process the milk or cream flows from the receiving tank to the pasteurizer, where it is heated to a temperature of from 160° to 165° F. in from 30 seconds to 1 minute, and from thence direct to the coolers, where it is cooled.

It is obvious that there is more heat required to pasteurize a given amount of milk or cream in the latter process than in the former; for example, assuming that the initial temperature of the incoming milk is 60° F. and that in the holder process it is heated to 150° F. and in the flash process to 165° F., then for every 1,000 pounds of milk to be pasteurized by each of these processes the actual number of heat units required to raise the temperature of the milk to the pasteurizing temperature is:

$$\text{B. t. u.}^1 = 1,000 \times 0.95^2 (150 - 60) = 85,500, \text{ holder process.}$$

$$\text{B. t. u.} = 1,000 \times 0.95 (165 - 60) = 99,750, \text{ flash process.}$$

It will be noted from the above figures that the flash process of pasteurization requires 16.6 per cent more heat to pasteurize a given

¹ B. t. u. (British thermal unit) is the quantity of heat required to raise 1 pound of pure water 1° F. at or near its maximum density, 39.1° F. For practical purposes, however, it may be considered the heat required to raise the temperature of 1 pound of water 1° F.

² The specific heat of milk is taken as 0.95. The specific heat of any substance is its capacity for absorbing heat compared with that of water taken as unity.

NOTE.—This bulletin deals with the cost of pasteurization from an engineering point of view. It contains desirable information for proprietors of creameries and milk plants and for designers and manufacturers of pasteurizing apparatus.

amount of milk than the holder process. Furthermore, the milk must be cooled through a correspondingly wider range. These figures, however, deal only with the heat absorbed by the milk, and do not take into consideration that radiated to the air and absorbed by the metal and other materials used in the construction of the apparatus.

TESTS OF MILK-PASTEURIZING APPARATUS.

The following tests were made on the pasteurizing equipment of five city milk plants. They were considered as representing average city plants. The pasteurizing equipment in each case consisted of heater, holding tank, regenerator, and cooler. In plants 1 and 2 the heater and regenerator were combined in one unit, and in plants 3, 4, and 5 they were separate. In plant 3 the regenerator was in the form of an ordinary tubular cooler, and the hot milk from the holding tank was pumped through the coils while the cold raw milk flowed over the tubes. In plants 4 and 5 the regenerators consisted of double-pipe arrangements, the hot milk flowing through the inner pipe and the cold milk through the outer and therefore surrounding the inner pipe.

The boilers were in good condition and were provided with exhaust steam feed-water heaters which heated the boiler feed water from an initial temperature of 60° F. to a final temperature of 180° F. The boiler pressure in all cases was approximately 80 pounds. The efficiency of the boiler and setting is assumed to be 50 per cent in all cases, which is believed to be a fair average. However, if there was a variation of 10 per cent in the estimated efficiency of the boiler and setting, it would affect the cost of pasteurization by approximately one-half of 1 per cent. It is further assumed that the coal cost \$4 per ton (2,240 pounds) delivered in the bunker and that it had a heat value of 12,500 B. t. u. per pound.

The condensed steam was caught as it came from the heater and weighed and its temperature taken, the average temperature being 180° F. The pressure of the steam entering the heater was reduced from the boiler pressure of 80 pounds gauge to from 3 to 5 pounds. Therefore, the heat absorbed in the heater per pound of steam supplied was $1,155 - (180 - 32) = 1,007$ B. t. u. For the sake of simplicity the heat absorbed in the heater per pound of steam supplied is taken as 1,000 B. t. u.

The temperatures of the milk were taken at each stage of the process and are recorded in Table 1, "Temperature balance." It will be noted from an inspection of the temperature balance that the cycle of operation consisted in starting with the initial temperature of the raw milk and raising its temperature to the pasteurizing point, about 145° F., then cooling the milk down to the temperature of the raw milk.

No account was taken of the cooling below the temperature of the milk in the receiving vat, as this had nothing to do with the pasteurizing cycle.

Based on the foregoing data and assumptions the following calculations are made:

TABLE 1.—Results of tests at five milk-pasteurizing plants.

	Plant number.				
	1	2	3	4	5
HEATING.					
Time of operation.....hours..	4.366	3.216	2.0	4.0	3.6
Amount of milk pasteurized.....pounds..	40,577	20,236	7,628	29,799	22,055
Amount of steam used in the pasteurizer, pounds.....	2,258	1,383	263.5	1,128	572.7
Heat in the steam supplied direct from the boiler to pasteurizer.....B. t. u..	2,601,595	1,593,405	305,499	1,299,542	659,796
Heat in the steam required to drive the pasteurizing equipment.....B. t. u..	1,006,259	444,704	276,519	921,664	829,439
Total heat supplied by boiler for pasteurizing.....B. t. u..	3,607,854	2,038,109	582,018	2,221,206	1,489,235
Heat absorbed in the pasteurizer.....do.....	2,258,000	1,383,000	263,500	1,128,000	572,700
Total boiler horsepower developed for pasteurizing.....B. H. P..	108.3	61.2	17.5	66.7	44.7
Boiler horsepower per hour developed for pasteurizing.....B. H. P..	24.8	19.0	8.75	16.7	12.4
Total heater horsepower consumed in pasteurizing.....B. H. P..	67.8	41.5	7.9	33.9	17.2
Heater horsepower per hour consumed in pasteurizing.....B. H. P..	15.6	12.9	3.9	8.5	4.8
Milk pasteurized per boiler horsepower, pounds.....	375	330	435	446	493
Milk pasteurized per heater horsepower, pounds.....	598	487	965	879	1,282
Coal consumed for pasteurizing, pounds.....	578	326	93	355	238
Milk pasteurized per pound of coal, do.....	70	62	82	84	93
COOLING.					
Cooling water required in water section of cooler.....cubic feet..	1,697	960	219	317	
Refrigeration extracted by brine, tons..	.48	.46	.206	1.70	.886
COSTS.					
Capital invested in pasteurizing equipment (pasteurizers, vats, coolers, etc.)..	\$5,332.00	\$3,000.00	\$2,065.00	\$3,470.00	\$6,250.00
Interest per day on investment at 6 per cent per annum.....	.876	.493	.339	.570	1.027
Depreciation and repairs per day at 25 per cent per annum.....	3.652	2.055	1.414	2.380	4.281
Capital invested in mechanical equipment used for pasteurizing (engine, boiler, shafting, etc.).....	1,000.00	800.00	300.00	500.00	700.00
Interest per day on investment at 6 per cent per annum.....	.164	.131	.049	.087	.115
Depreciation and repairs per day at 10 per cent per annum.....	.274	.219	.082	.137	.192
Labor, for pasteurizing.....	3.500	1.750	1.500	3.000	3.000
Cost of coal at \$4 per ton (2,240 pounds).....	1.032	.582	.166	.634	.425
Cost of cooling water at 50 cents per 1,000 cubic feet.....	.848	.480	.109	.158	.009
Cost of refrigeration at \$1 per ton.....	.480	.460	.206	1.700	.886
Cost of pasteurizing daily supply of milk.....	10.826	6.170	3.865	8.666	9.935
Cost of pasteurizing one gallon of milk.....	.00229	.00262	.00436	.00251	.00387
Average cost for the five plants of pasteurizing 1 gallon of milk.....	.00313				

TABLE 1.—Results of tests at five milk-pasteurizing plants—Continued.

HEAT BALANCE.

	1		2		3		4		5	
	Heat supplied.	Heat accounted for.	Heat supplied.	Heat accounted for.	Heat supplied.	Heat accounted for.	Heat supplied.	Heat accounted for.	Heat supplied.	Heat accounted for.
Total heat in steam supplied to pasteurizer.....	<i>P. ct.</i> 100.00	<i>P. ct.</i>	<i>P. ct.</i> 100.00	<i>P. ct.</i>	<i>P. ct.</i> 100.00	<i>P. ct.</i>	<i>P. ct.</i> 100.00	<i>P. ct.</i>	<i>P. ct.</i> 100.00	<i>P. ct.</i>
Heat returned by regenerator.....	43.86		41.00		151.87		124.76		264.27	
Heat remaining in liquid (condensed steam).....		14.51		14.51		14.62		14.64		14.62
Heat required to raise temperature of initial charge of water.....		1.92		2.41		5.56				
Heat lost in holder.....		11.79		5.09		5.38		2.91		12.42
Heat absorbed in regenerator by incoming milk.....		43.86		41.00		151.87		124.76		264.27
Heat absorbed in cooler in reducing temperature to that of raw milk.....		65.97		64.98		47.63		65.58		34.39
Loss in radiation, exclusive of holder.....		5.81		12.98		26.80		16.87		38.57
Total.....	143.86	143.86	141.00	141.00	251.87	251.87	224.76	224.76	364.27	364.27

TEMPERATURE BALANCE.

	1 ¹	2 ¹	3 ²	4 ³	5 ⁴
Raw milk.....°F.....	63.50	57.86	59.40	54.00	47.60
Regenerator.....°F.....			131.30	107.50	124.10
Rise in regenerator.....°F.....			71.90	53.50	76.50
Per cent rise.....per cent.....			84.00	60.53	78.30
Heater.....°F.....	146.00	150.40	145.00	142.40	145.30
Rise in heater.....°F.....	82.50	92.54	13.70	34.90	21.20
Per cent rise.....per cent.....			16.00	39.47	21.70
Total per cent rise.....per cent.....	100.00	100.00	100.00	100.00	100.00
Holder.....°F.....	146.00	150.40	145.00	142.40	143.30
Drop in holder.....°F.....	8.00	4.24	2.25	1.33	3.90
Per cent drop.....per cent.....	9.70	4.58	2.63	1.50	3.99
Regenerator.....°F.....	138.00	146.16	142.75	141.07	141.40
Drop in regenerator.....°F.....	29.75	34.16	63.45	57.07	83.00
Per cent drop.....per cent.....	36.00	36.85	74.12	64.50	84.96
Cooler.....°F.....	108.25	112.00	79.30	84.00	56.00
Drop in cooler.....°F.....	44.75	54.14	19.90	30.00	10.80
Per cent drop.....per cent.....	54.30	58.57	23.25	34.00	11.05
Total per cent drop.....per cent.....	100.00	100.00	100.00	100.00	100.00

¹ Regenerator in heater.² Surface cooler used as regenerator.³ Direct expansion coils in cooler.⁴ Cooled entirely by refrigerated water.

ECONOMY IN USE OF REGENERATORS.

Referring to the heat balance for the foregoing plants in which regenerators, or heat exchangers, were used, it will be noted that in some cases the heat returned by the regenerator is considerably in excess of the total amount supplied by the heater. It should be borne in mind, however, that this heat is exchanged from the hot milk leaving the holder to the cold incoming milk, the heat supplied by the steam going to make up the losses; consequently the greater the efficiency of the regenerator the less heat is required from the steam. The hot milk from the holder is transferred to the cooler usually through the inner pipe of the regenerator; consequently

the milk entering the heater is thus heated, while that entering the cooler is partly cooled, the cooler proper reducing the temperature to the point desired. The function of the regenerator is therefore to economize heat by transferring the heat from the hot to the cold milk. The hot milk coming from the heater flows into the holding vat and is here held for about 30 minutes. It then flows through the regenerator to the cooler, where it is cooled by water and brine circulation, direct expansion of ammonia in the cooler pipes sometimes being used instead of brine.

Just the reverse is true in the case of the cold milk; that is, the cold milk comes from the receiving vat, where it is at a temperature of about 55° F., and goes through the outer coils of the regenerator, where it is heated by the returning hot milk. It is obvious, therefore, that any heat transferred from the hot to the cold milk represents just so much gain in economy. If it were possible to transfer all the heat in the hot milk above the initial temperature of the raw to the cold incoming milk after the first charge had been once heated to the pasteurizing temperature, the heater could be dispensed with entirely, and the pasteurizing would go on indefinitely. This would constitute, however, a theoretically perfect machine, which is an impossibility; but the more perfect the regenerative apparatus the less heat will have to be supplied by the heater. The heat balance in test No. 5 shows that it would have taken over two and a half times the heat had no regenerator been used.

In all of the foregoing tests the pasteurizing was done with live steam taken direct from the boiler but reduced in pressure to from 3 to 5 pounds. Subsequent tests show that the pasteurization could just as well have been done with exhaust steam, and by so doing a load of from 8.75 to 24.8 boiler horsepower could have been taken off the boiler plant except in plant 1, where the exhaust steam was utilized for making ice in an absorption ice plant.

Attention is invited to the saving obtained by the use of regenerators in the foregoing tests. The boiler horsepower per hour required for pasteurizing in tests Nos. 1, 2, 3, 4, and 5 was 24.8, 19, 8.75, 16.7, and 12.4, respectively. Without the regenerator, or heat exchanger, the boiler horsepower per hour required for pasteurizing would have been increased to 35.6, 26.78, 22, 37.5, and 45.1, respectively. Thus the average increase in fuel would have been 96.8 per cent, or practically doubled. In addition to the direct saving in fuel due to exchanging the heat from the hot milk coming from the holding tank to the cold raw milk on its way to the heater, there is an average saving in refrigeration of approximately 60 per cent, for it is evident that the heat taken out of the hot milk in the regenerator takes just so much work off the cooler. By referring to the temperature balance in the table it will be noted that the drop in temperature in the

regenerator varied from $29\frac{3}{4}^{\circ}$ to 83° F., an average of $53\frac{1}{2}^{\circ}$ F. In other words, the milk arrived at the cooler $53\frac{1}{2}^{\circ}$ F. lower in temperature than it would have done had no regenerator been used.

The regenerator is an efficient piece of apparatus when viewed from an engineering standpoint, but it has its disadvantages when viewed from the bacteriological standpoint, as it is difficult to keep absolutely clean and sterile unless given particular attention.

DEPRECIATION OF DAIRY EQUIPMENT.

Owing to the rough usage to which dairy apparatus is subjected, having to be taken apart for the purpose of thorough cleaning after each operation, and to the rapid development and improvement in this line of apparatus, it is assumed that about four years is its average useful life, at which time it is either worn out or antiquated and must be replaced. Therefore, it has been depreciated at the rate of 25 per cent per annum.

The mechanical equipment (engine, boiler, shafting, etc.) necessary for the operation of the pasteurizing apparatus and which has been depreciated at the rate of 10 per cent per annum covers only that part of the total equipment which is used for pasteurizing. In other words, the total value of the mechanical equipment of the plant is prorated among the various processes through which market milk passes in a modern city milk plant.

TESTS OF CREAM-PASTEURIZING APPARATUS.

Tests made on the pasteurizing equipment in creameries covered both the flash and the holder processes. The pasteurizing was also accomplished by using (1) live steam direct from the boiler, (2) exhaust steam from the engine or from steam-driven pumps, and (3) hot water heated by the exhaust steam from the steam-driven auxiliaries.

In calculating the heat absorbed by the cream in the following tests, the specific heat of cream is taken as 0.90. In this connection it is well to state that there seems to be very little known at the present time concerning the specific heat of cream. It does, of course, vary to a certain extent with its chemical and physical composition. At a certain point on the temperature scale its specific heat is greatly increased, apparently above unity. This is attributed, however, to the melting of the butterfat and a part of the absorbed heat being used to effect the change.

In Table 2 are given the results of tests on the pasteurizing equipment of four creameries. The tests were made under actual working conditions. In tests Nos. 1, 2, and 3 the pasteurizing was done by employing exhaust steam and in test No. 4 live steam was taken direct from the boiler through a reducing valve.

TEST NO. 1.

Referring to test No. 1, the pasteurizing was done with hot water which was heated by exhaust steam from five steam-driven turbine separators and five reciprocating steam pumps. The arrangement for utilizing the heat in the exhaust steam is illustrated diagrammatically in figure 1. As it was impracticable to put a back pressure on the small steam turbines used for driving the separators, as would be done if they were allowed to exhaust under water or into a milk heater, the arrangement shown was resorted to. The exhaust from the separators and pumps was piped into the box above the water level. The hot-water circulating pump took the water from the box and forced it through the internal tubular heater and back into the box. The spray pipe, located in the top of the box, above the water level, was

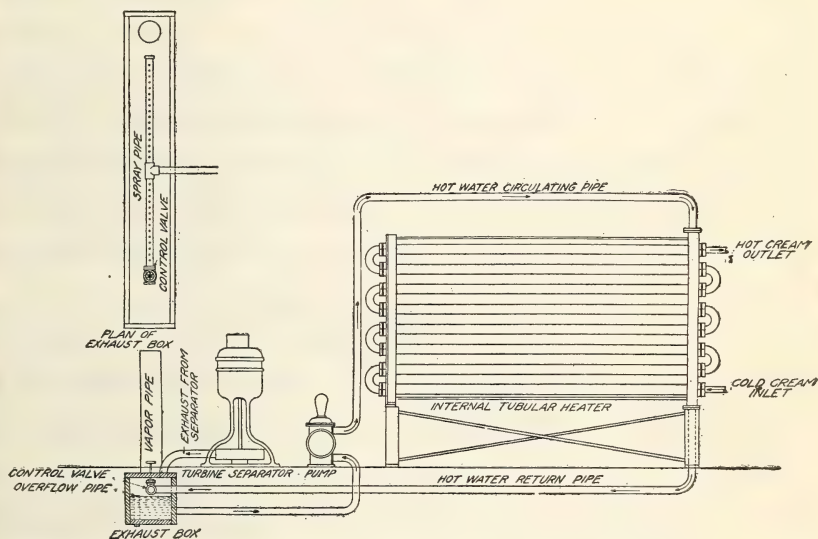


FIG. 1.—Elementary diagram of hot water pasteurizing equipment.

perforated with a large number of small holes through which the return water was sprayed. The heat contained in the exhaust steam was taken up by the water, the equipment acting on the principle of the jet condenser. There was a valve placed on the end of the spray pipe for controlling the temperature of the water. By opening this valve the return water was allowed to pour out into the box without absorbing much heat from the steam, while, on the other hand, if the valve was closed all of the return water was sprayed, thereby absorbing the maximum amount of heat. The temperature of the water was controlled very satisfactorily by this arrangement. There was an overflow pipe placed in the box, as indicated, which kept the water at a constant level by allowing the condensed steam to overflow into the sewer. There was a vapor pipe on one end of the box which

allowed the uncondensed steam to escape to the atmosphere. The exhaust box was built up of cypress lumber, being about 12 inches square by 14 feet long. The heat contained in the exhaust steam from the five steam turbine driven separators and five reciprocating pumps was sufficient for pasteurizing 17 per cent cream at the rate of 18,360 pounds, or 9.18 tons, per hour. This was actually done during the first hour of test. The initial temperature of the cream was 49.5° F., and it was raised to a pasteurizing temperature of 147° F., or through a range of 97.5° F.

As 1 boiler horsepower is equivalent to the evaporating of 34½ pounds of water from and at 212° F., the boiler horsepower per hour required for pasteurizing under the above conditions was 67.1. It is therefore obvious that had this exhaust steam been allowed to go to waste and live steam been taken direct from the boiler for pasteurizing, the boiler capacity of the plant would have had to be increased by this amount, viz., 67.1 horsepower. In other words, there was a saving in boiler capacity, by using the heat in the exhaust steam for pasteurizing, of 67.1 horsepower. As has been previously explained, it was necessary to employ some such arrangement as that illustrated in the diagram in order to avoid putting a back pressure on the turbine separators, although this arrangement entailed a loss of heat due to the double heat transfer from the exhaust steam to the water and from the water to the cream.

Assuming that the boiler and furnace efficiency was 50 per cent and that the coal used had a heating value of 12,500 B. t. u. per pound, then the fuel saved per hour with this arrangement is $\frac{67.1 \times 34.5 \times 970.4}{12,500 \times .50} = 359$ pounds. If the pasteurizing equipment is run 4 hours a day for 310 days in the year, the annual saving in fuel is $\frac{359 \times 4 \times 310}{2,240} = 198.7$ tons, which at \$4 per ton would amount to \$794.80. In addition to the fuel saved, there is a further saving due to the decreased boiler capacity of the plant.

It is evident that if the exhaust steam from the separators and pumps had been allowed to escape it would have been necessary to have taken live steam from the boilers for the purpose of pasteurizing, and this would have taken an additional 70-horsepower boiler, which would have cost approximately \$14.75 per boiler horsepower installed, or \$1,032.50. Figuring the interest on the money invested at 6 per cent per annum and depreciation and repairs at 10 per cent, there is a saving in addition to the fuel of \$165.45, making a total saving of \$794.80 + \$165.45 = \$960.25, to say nothing of the increased labor of firing the boiler. Adding this to the actual cost would bring the cost of pasteurizing 100 pounds of cream in this particular plant up to \$0.0512, or an increase of 12.3 per cent. The fuel cost,

however, is practically doubled when steam is taken direct from the boiler for pasteurizing instead of utilizing the exhaust steam. The steam pressure is reduced from boiler pressure to about 3 pounds by some form of reducing valve, consequently there is approximately as much heat in the exhaust steam from the engine, or steam-driven auxiliaries, as there is in steam taken from the boiler. The amount of fuel mentioned above is for pasteurizing, and is not to be confused with the total amount used in firing the boilers. In other words, it is the fuel required to evaporate in the boiler a certain amount of water which is used for the purpose of pasteurizing the cream. With this arrangement the pasteurizing was done with heat that would otherwise have been wasted, and furthermore it took a load of 67.1 horsepower off the boiler plant.¹

TESTS NOS. 2, 3, AND 4.

Tests Nos. 2 and 3 were also made with exhaust steam, but the arrangements were different from the foregoing, as the exhaust from the engines was piped directly into the heater. The only load on the engines at the time was the pasteurizers and the centrifugal cream separators, which amounted to very little. The exhaust steam available, however, was sufficient to operate the pasteurizers up to their full capacity.

Referring to the summary of the tests in Table 2 it will be noted that the fifth item, "Heat in steam required to drive pasteurizing equipment," is blank except for test No. 4. The reason for this is that the engine or steam-driven auxiliaries from which exhaust steam was used for pasteurizing are considered in the light of pressure-reducing valves, the mechanical power being, so to speak, a by-product. That is to say, there is a loss of heat in steam due to drop in pressure, and while the wire drawing of the steam through the valve will superheat the steam to a certain extent, the loss may be considered the same for the purpose of this paper, regardless of whether this drop is caused by passing through a pressure-reducing valve or through a steam engine. In test No. 4 the steam used for pasteurizing was reduced in pressure by a valve, consequently the energy represented by the difference in pressure and temperature of the steam before and after passing through the reducing valve is a clear loss. In neither case, however, was the heat lost due to drop in pressure of the steam available for heating the cream. The 380,800 B. t. u. in column 4 represents the heat in the steam at boiler pressure which was used in the engine for driving the pasteurizer, separator, shafting, etc., required in the process of pasteurizing, and as the exhaust from the engine was allowed to go to waste it is

¹ The use of exhaust steam for other purposes in milk plants is treated in Bureau of Animal Industry Circular 209.

obvious that the 380,800 B. t. u. represented so much additional heat over the exhaust-steam systems in tests Nos. 1, 2, and 3.

As stated above, in test No. 4 the pasteurizing was done by live steam from the boiler instead of exhaust steam, and by referring to the tabulated results of tests it will be noted that the over-all thermal efficiency of test No. 4 is only 43.7 per cent while that of tests Nos. 1, 2, and 3 is 69.1, 60.6, and 69.7 per cent, respectively, although the thermal efficiency of the heater in test No. 4 was the greatest.

The over-all efficiency is here taken as the ratio of the heat supplied by the boiler to the steam to that absorbed by the cream.

The thermal efficiency of the heater is the ratio of the available heat in the steam supplied to the heater to that absorbed by the cream.

HEAT BALANCE.

No heat balance is given in Table 2 because the pasteurizing equipments in tests Nos. 1, 2, and 3 were installed in market cream plants, that is, plants whose business consisted in the handling and marketing of cream. The cream as received from auxiliary creameries was first run through separators, the result being a heavy cream containing about 40 per cent fat. This heavy cream on the way to the coolers was mixed with skimmed milk in the correct proportion to produce a cream containing a predetermined amount of fat. In view of the methods employed in these plants, it was impractical to get out a heat balance showing the distribution of heat in the pasteurizing cycle.

TABLE 2.—Results of tests of four cream-pasteurizing plants.

HEATING.

	Plant No.			
	1	2	3	4
Time of operation.....hours.....	3.53	1.733	1.5	1.166
Amount of cream pasteurized.....pounds.....	50,683	6,928	5,019.5	4,571
Amount of steam used in the pasteurizer.....do.....	5,589.5	1,088	647.5	529
Heat supplied by boiler to steam, 80 pounds pressure, B. t. u.....	6,437,646	1,253,478	746,003	617,113
Heat in steam required to drive pasteurizing equipment, B. t. u.....				380,800
Heat supplied to pasteurizer.....do.....	5,589,500	1,088,000	647,500	529,000
Total boiler horsepower developed for pasteurizing, B. H. P.....	193.2	37.6	22.4	29.9
Boiler horsepower per hour developed for pasteurizing, B. H. P.....	54.7	21.7	14.9	25.6
Total heater horsepower consumed for pasteurizing.....do.....	167.7	32.6	19.4	15.9
Heater horsepower per hour consumed for pasteurizing, B. H. P.....	47.5	18.8	13.0	13.6
Cream pasteurized per boiler horsepower.....pounds.....	262	184	224	153
Cream pasteurized per heater horsepower.....do.....	302	212	258	287
Coal burned in pasteurizing.....do.....	1,030	200	119	160
Cream pasteurized per pound of coal.....do.....	49.2	34.6	42.2	29.0
Total B. t. u. absorbed by cream.....B. t. u.....	4,447,433	760,030	520,171	436,176
The over-all thermal efficiency of pasteurizing equip- ment.....per cent.....	69.1	60.6	69.7	43.7
Thermal efficiency of heater.....do.....	79.4	69.8	80.3	82.5

TABLE 2.—Results of tests of four cream-pasteurizing plants—Continued.

COOLING.

	Plant No.			
	1	2	3	4
Cooling water used in water section of cooler, cubic feet.....	1,877	704	169	148
Ice used in cooling cream to its original temperature, tons.....	3.44	.92	.83	1.72

COSTS.

Capital invested in pasteurizing equipment (pasteurizer, vats, coolers, etc.).....	\$7,400.00	\$1,255.00	\$600.00	\$700.00
Interest per day on investment at 6 per cent per annum.....	1.233	.206	.098	.115
Repairs and depreciation per day at 25 per cent per annum.....	5.068	.586	.411	.489
Capital invested in mechanical equipment used for pasteurizing (engine, boiler, shafting, etc.).....	1,350.00	1,000.00	500.00	800.00
Interest on investment per day at 6 per cent per annum.....	.222	.164	.082	.131
Repairs and depreciation per day at 10 per cent per annum.....	.370	.274	.137	.219
Labor for pasteurizing.....	10.000	2.000	2.000	2.000
Cost of coal at \$4 per ton (2,240 pounds).....	1.839	.357	.203	.285
Cost of cooling water at 50 cents per 1,000 cubic feet.....	.938	.352	.084	.074
Cost of refrigeration at \$1 per ton.....	3.440	.920	.830	1.720
Cost of pasteurizing daily supply of cream.....	23.110	4.857	3.845	5.033
Cost of pasteurizing 1 gallon of cream.....	.00378	.00582	.00636	.00939
Cost of pasteurizing 100 pounds of cream.....	.0456	.0701	.0765	.1101
Average cost of pasteurizing 1 gallon of cream in the four tests.....	.00634			
Average cost of pasteurizing 100 pounds of cream in the four tests.....	.0756			

TEMPERATURE BALANCE.

	1	2	3 ¹	4 ²
Temperature of raw milk.....°F..	49.5	42.0	39.3	56.25
Temperature of milk in heater.....°F..	147.0	169.6	160.2	167.25
Rise of temperature in heater.....°F..	97.5	127.6	120.9	111.00
Total per cent rise.....per cent..	100	100	100	100
Temperature of milk in holder.....°F..	147.0	169.6		
Drop of temperature in holder.....°F..	3.0	³ 16.8		
Per cent drop in holder.....per cent..	3.1	³ 13.2		
Temperature of milk in separator.....°F..	144.0	152.8	160.2	
Drop of temperature in separator (milk).....°F..	9.2	7.2	1.8	
Per cent drop in separator (milk).....per cent..	9.4	5.6	1.5	
Drop of temperature in separator (cream).....°F..	12.8	15.3	5.0	
Per cent drop in separator (cream).....per cent..	13.2	12.0	4.1	
Temperature of milk in cooler.....°F..	134.8	145.6	158.4	
Drop of temperature in cooler (milk).....°F..	85.3	103.6	119.1	
Per cent drop in cooler (milk).....per cent..	87.5	81.2	98.5	
Temperature of cream in cooler.....°F..	131.2	137.5	155.2	167.25
Drop of temperature in cooler (cream).....°F..	81.7	95.5	115.9	111.00
Per cent drop in cooler (cream).....per cent..	83.7	74.8	95.9	
Total per cent drop.....do.....	100	100	100	100

¹ No holder.² No holder or separator.³ Large drop in holder was due to stirring apparatus.

The summary of the tests in Table 2 gives the cost of pasteurizing at the different plants under the conditions at which each particular plant was operating at the time of the test. Therefore the cost of pasteurizing 100 pounds of cream will vary slightly in the different plants due to the varying conditions. It will be noted from an inspection of the temperature balance that the initial temperature of the raw cream varied in the different plants and also the final or pasteurizing temperatures. In order to make a comparison of cost

it becomes necessary to put them all on an equal basis, so far as it is possible to do so, and for this purpose it is assumed that the pasteurizing cycle consisted in raising and lowering the temperature of the cream through a range of 100° F., all other conditions remaining the same. The cost of pasteurizing 100 pounds of cream in the different plants, corrected as above, is \$0.0459, \$0.0650, \$0.0726, and \$0.1056 for tests Nos. 1, 2, 3, and 4, respectively.

The amount of cream handled will, of course, affect the unit cost to a great extent, as may be gathered from the summary of tests.

Referring to test No. 4, the power required for driving the pasteurizing equipment was excessive, as a considerable amount of line shafting was uselessly driven while pasteurizing. This, together with taking steam from the boiler through a reducing valve instead of using the heat from the exhaust steam, accounts for the high cost of pasteurizing at this plant.

CONCLUSIONS.

The conclusions drawn from the foregoing tests are as follows:

1. The flash process of pasteurization requires approximately 17 per cent more heat than the holder process. There is a correspondingly wider range through which the milk or cream must be cooled, both adding extra cost to the pasteurizing cycle.

2. The proper design and arrangement of the heater, regenerator, cooler, piping, and refrigerating apparatus have much to do with the efficient operation of the plant.

3. With poorly arranged apparatus and leaky piping the loss in heat may reach approximately 30 per cent of that required to pasteurize, which it is practicable to reduce to a negligible amount.

4. It is practicable to use exhaust steam from the engine and steam-driven auxiliaries, or water heated by exhaust steam, to furnish heat with which to pasteurize both milk and cream.

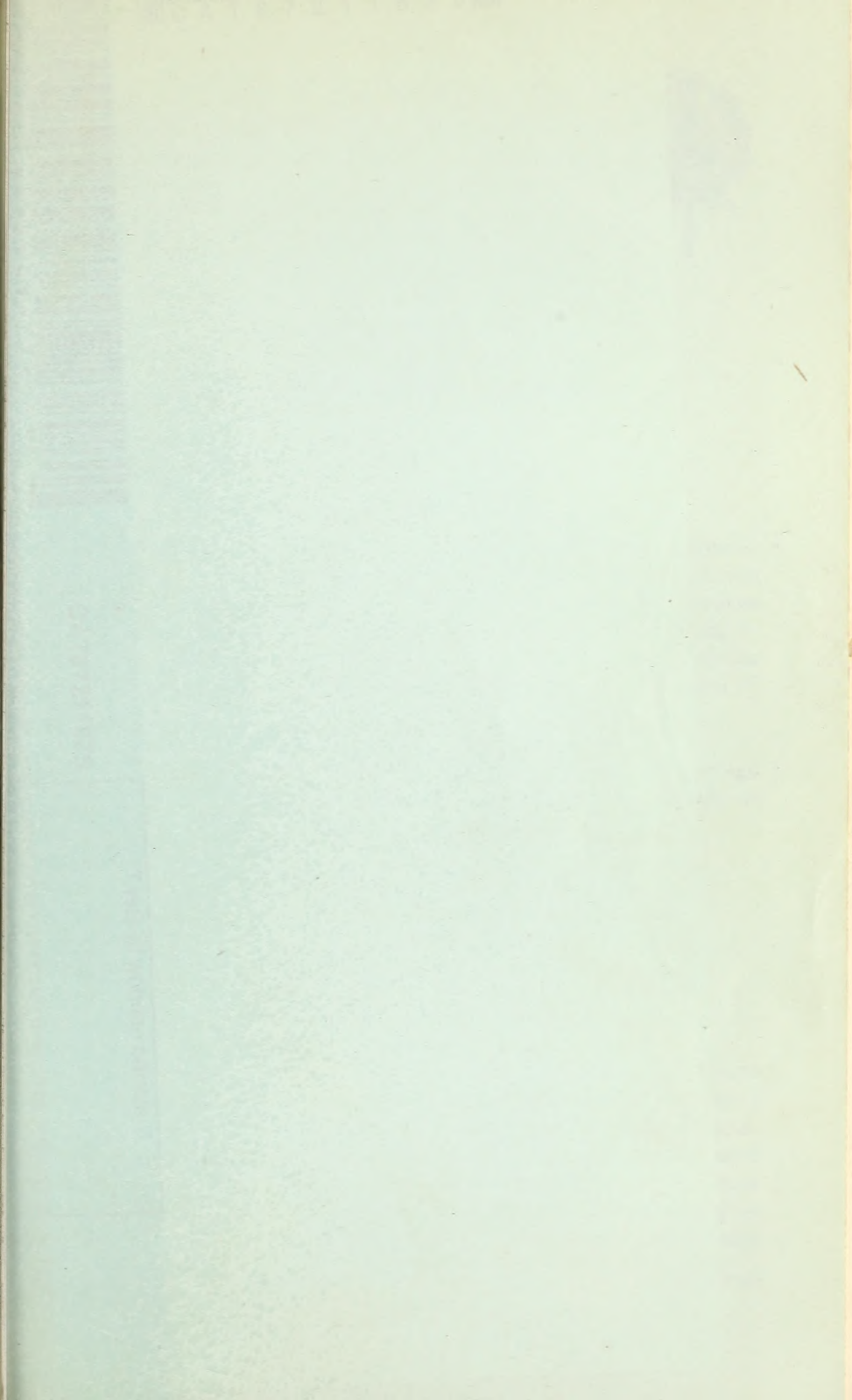
5. Usually there is sufficient heat in the exhaust steam which is allowed to waste in milk plants and creameries to do the pasteurizing.

6. For every 400 pounds of milk pasteurized per hour with exhaust steam, approximately one horsepower is taken off the boiler plant.

7. The average cost of pasteurizing 1 gallon of milk is shown to be \$0.00313.

8. The average cost of pasteurizing 1 gallon of cream is shown to be \$0.00634, or \$0.0756 per 100 pounds.

9. It must be understood that the cost of pasteurizing as figured in this paper deals only with the pasteurizing cycle, viz, starting with the initial temperature of the raw milk and raising its temperature to the pasteurizing point, then cooling the milk down to the initial temperature of the raw milk. In other words, it has been attempted to show the additional expense encountered in producing pasteurized milk and cream over the raw product.



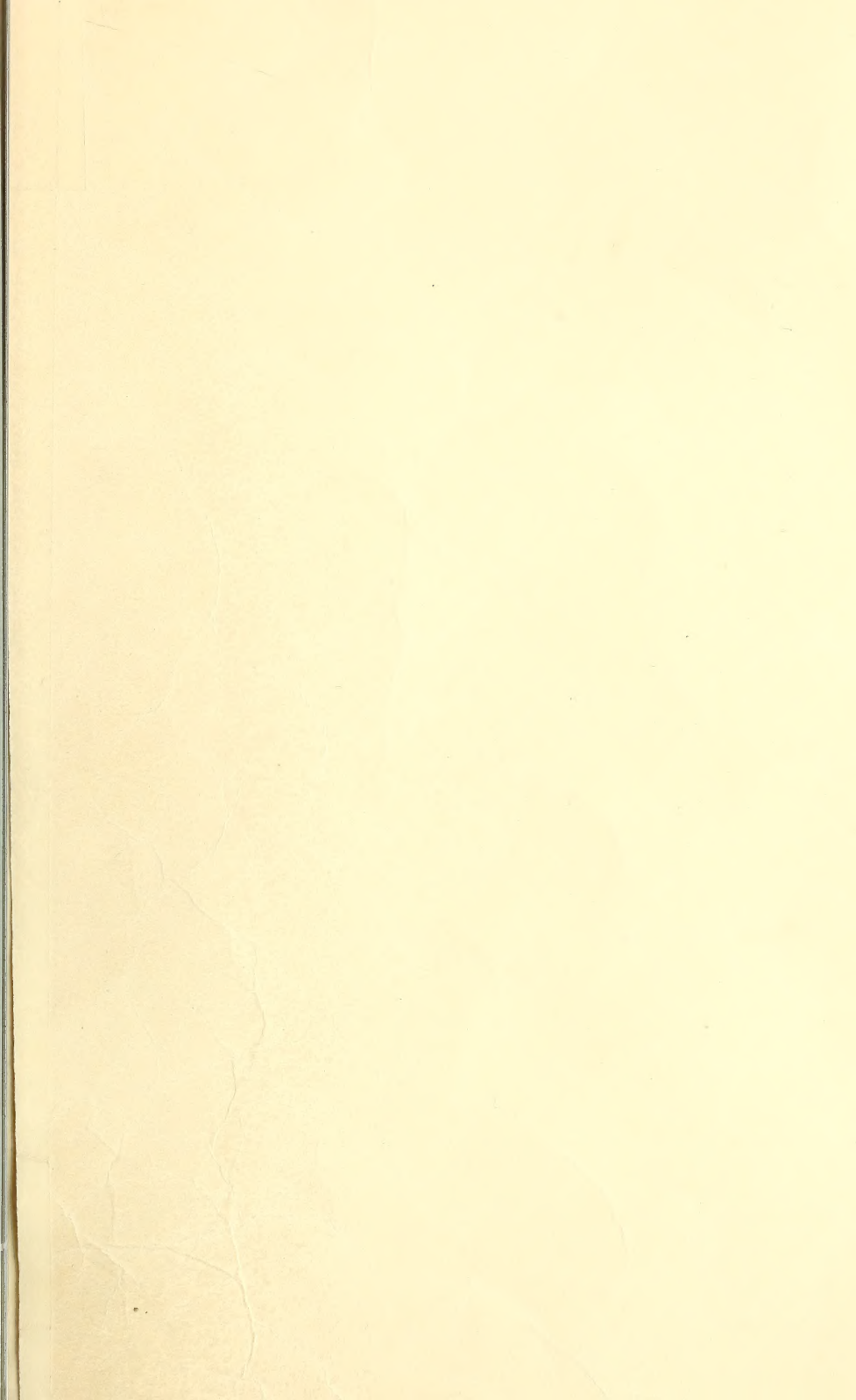
the first of these, the fact that the United States is a young nation, and that its history is a history of growth and expansion, is a fact which is not only true, but also one which is of great importance in the study of the history of the world. The second of these, the fact that the United States is a nation of immigrants, is also a fact which is of great importance in the study of the history of the world. The third of these, the fact that the United States is a nation of free men, is also a fact which is of great importance in the study of the history of the world.

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CHAPTER I

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